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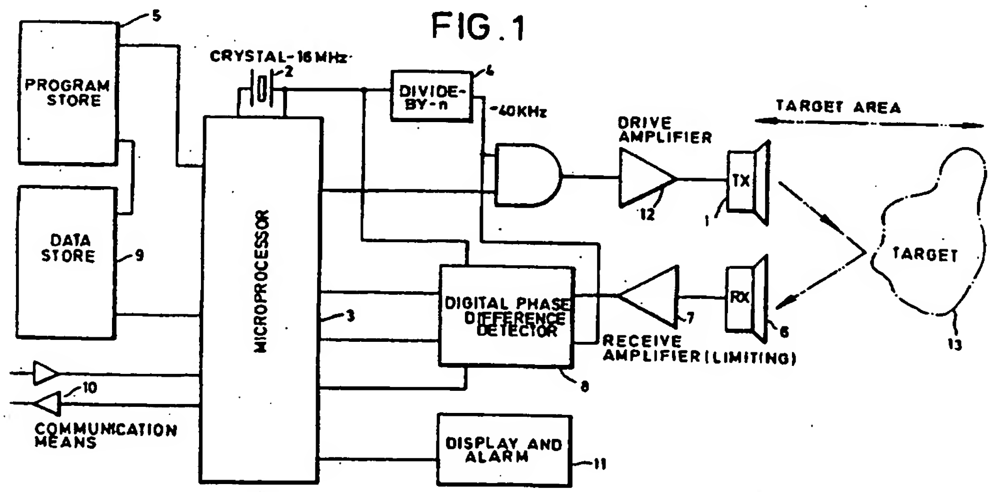
(54) Ultrasonic monitor

(57) Ultrasonic monitors are described which are developments of those described in WO94/20021. Bursts of ultrasound pulses are periodically emitted into a monitored zone by an emitter (TX) and reflections from objects in the room are received by a receiver (RX). The phase of individual pulses of the reflected waves are measured relative to the phase of the transmitted waves in order to produce a phase-time profile (Figure 19) for each cycle corresponding to a respective burst of transmitted pulses. Individual objects in the field of view can be identified by their characteristic shape or sub-profile in the phase-time profile.

The monitor can be arranged as an intruder alarm in a room by arranging for the sub-profiles in the phase-time profile to be compared with the parameters of sub-profiles representative of an intruder. False alarms associated with small objects close to the emitter/detector can be avoided by measuring the size of the object in various ways. The monitor can also be used to detect removal of a specific object from a monitored zone, for example removal of a baby from a crib.

A fire can also be detected by detecting a time-shift of the entire phase-time profile.

FIG.1



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1995

GB 2 299 405 A

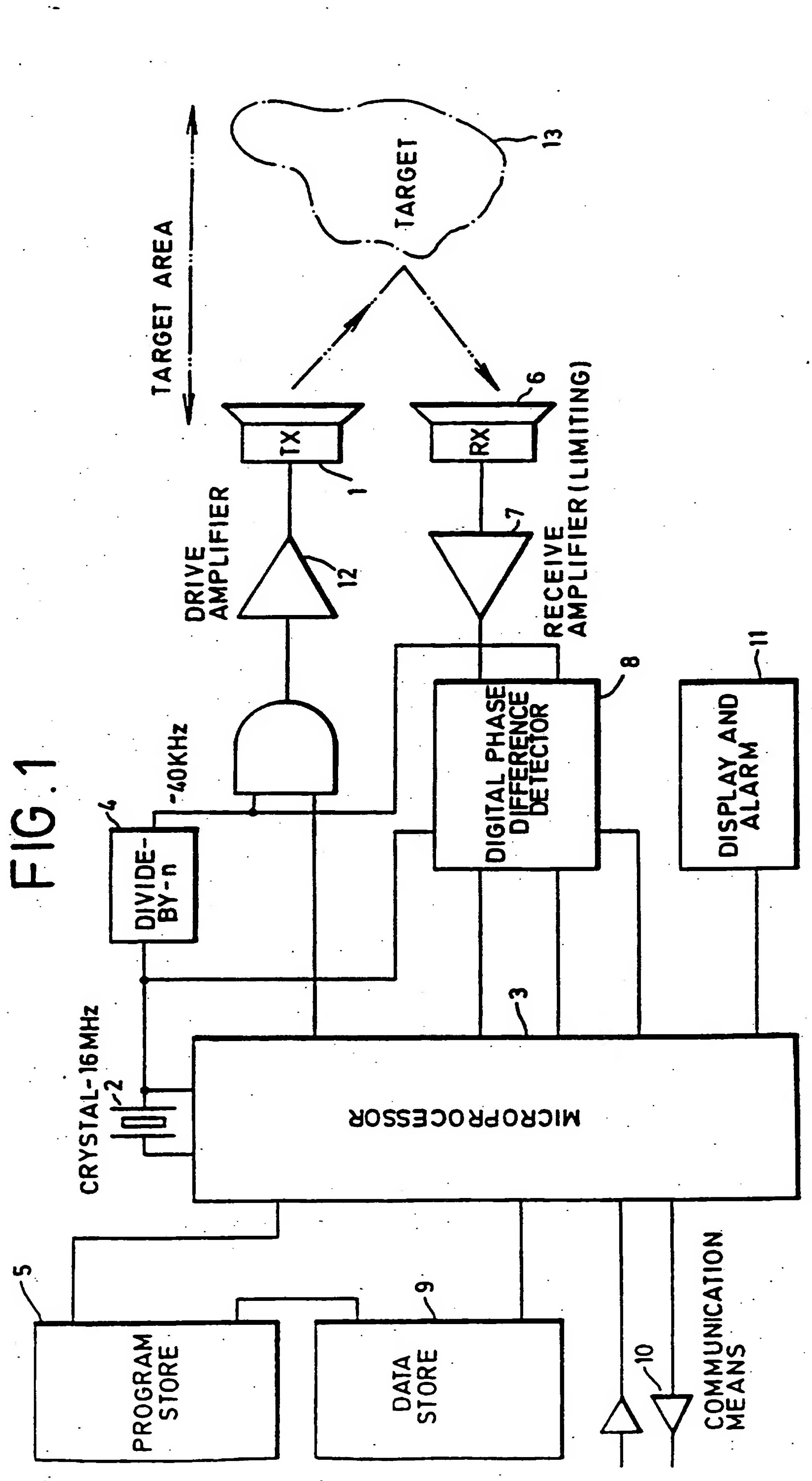

TARGET AREA
TARGET
13
TX
1
RX
6
DRIVE AMPLIFIER
12
RECEIVE AMPLIFIER (LIMITING)
7
~40KHz
DIVIDE-BY-n
4
DIGITAL PHASE DIFFERENCE DETECTOR
8
DISPLAY AND ALARM
11
CRYSTAL-16MHz
2
MICROPROCESSOR
3
PROGRAM STORE
5
DATA STORE
9
COMMUNICATION MEANS
10

FIG. 1

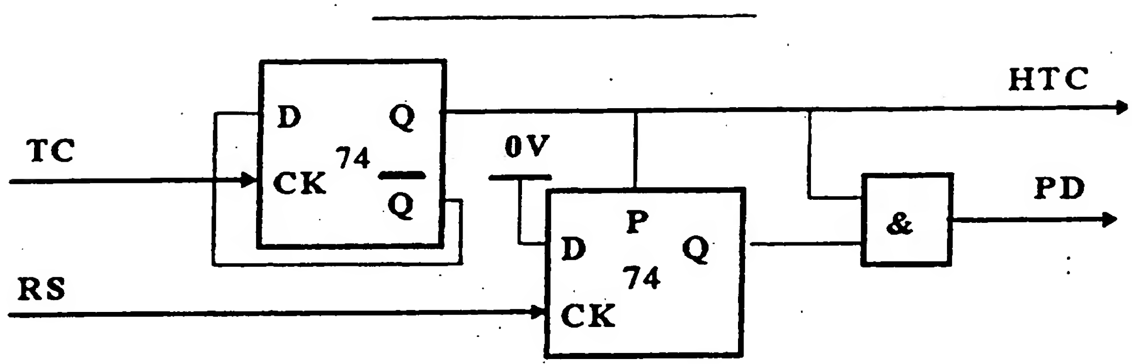


Fig. 2

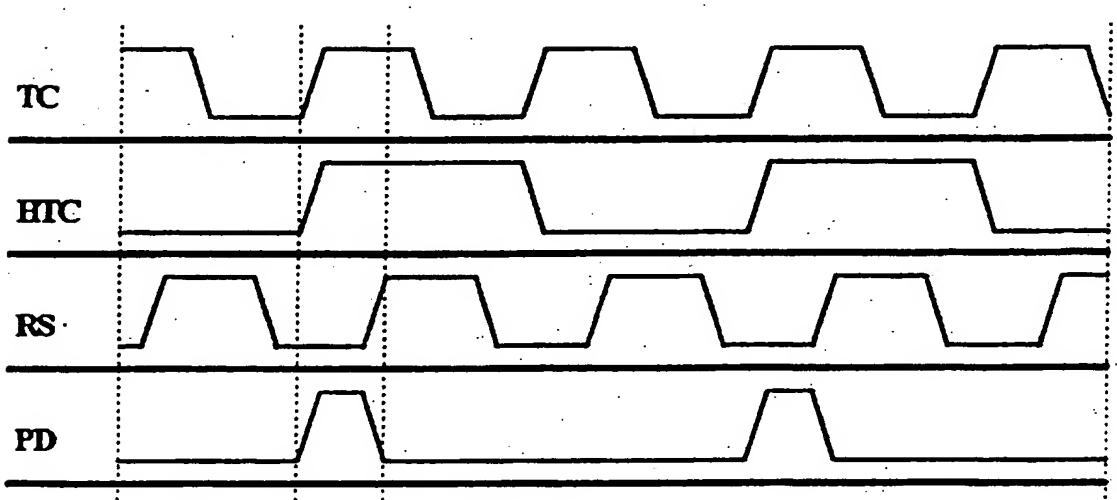


Fig. 3

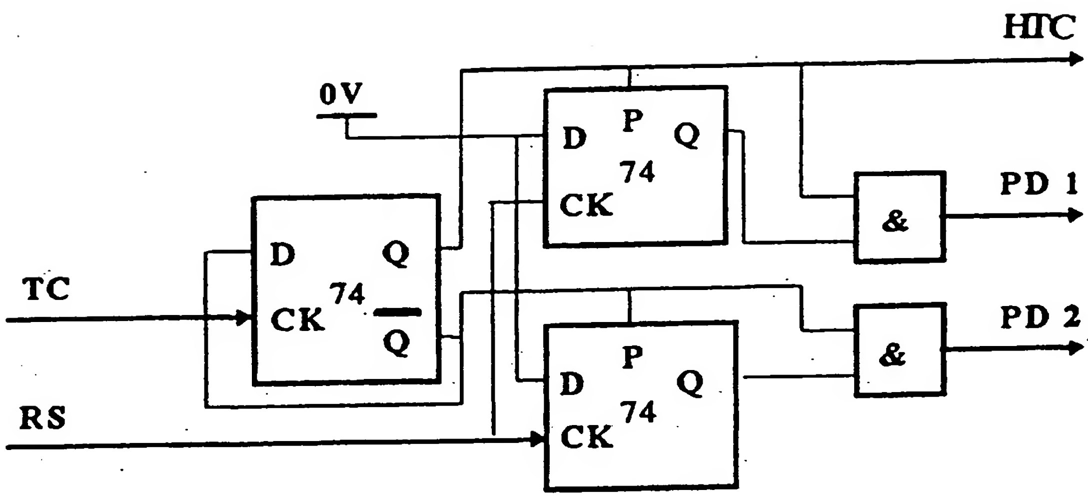


Fig. 4

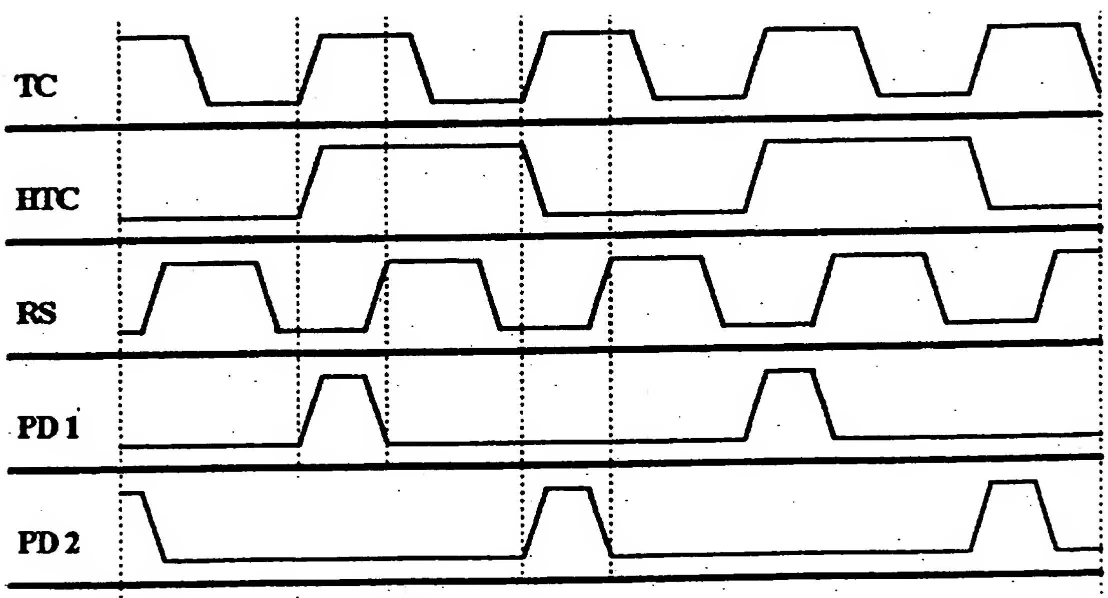


Fig. 5

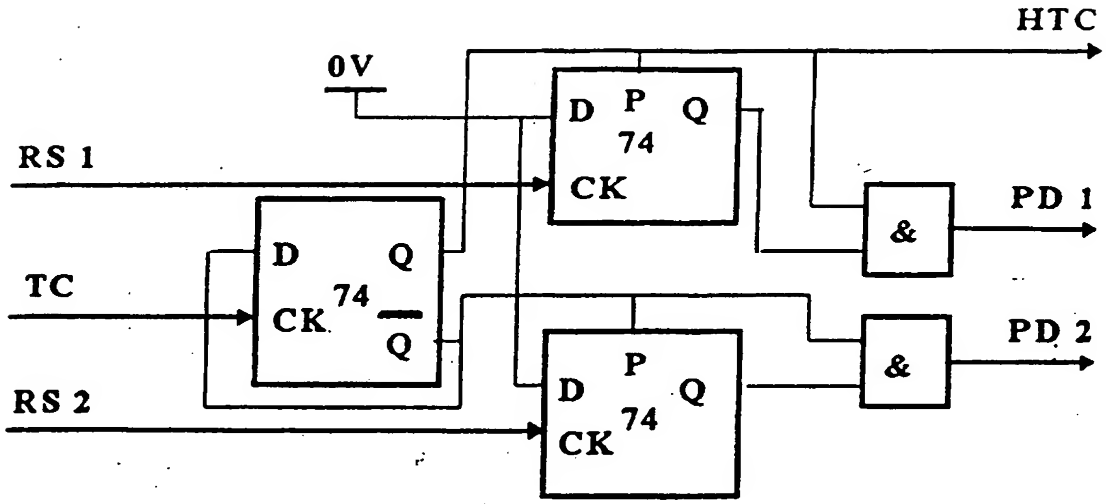

HTC
0V
RS 1
TC
RS 2
D
Q
74
CK
Q
D
P
Q
74
CK
D
P
Q
74
CK
&
&
PD 1
PD 2

Fig. 6

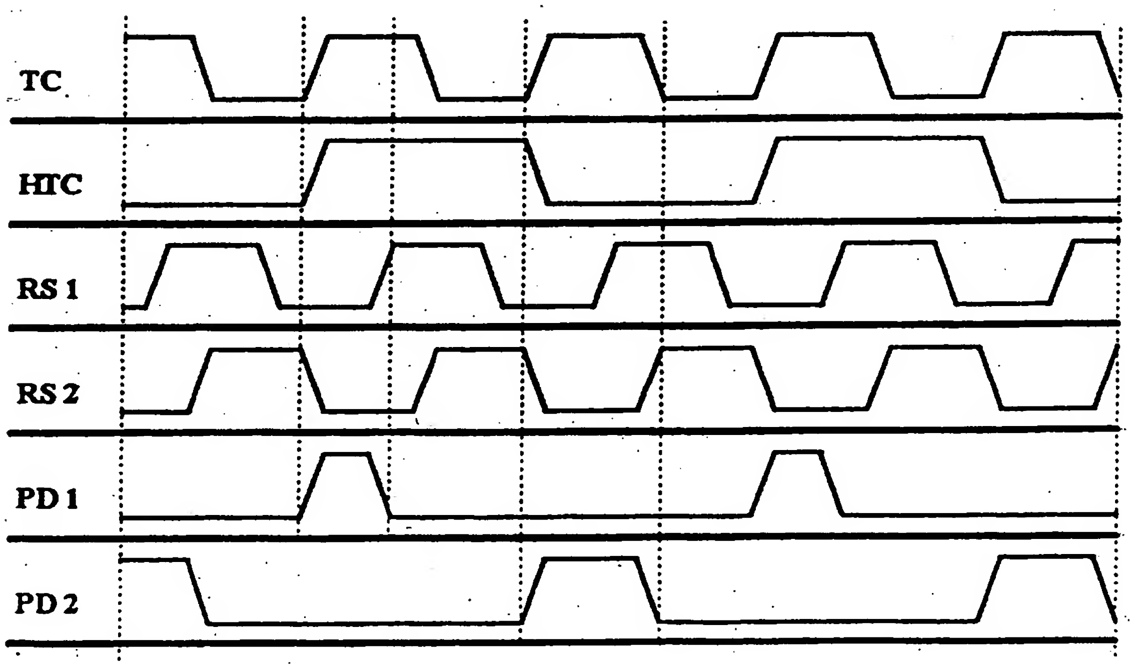

TC
HTC
RS 1
RS 2
PD 1
PD 2

Fig. 7

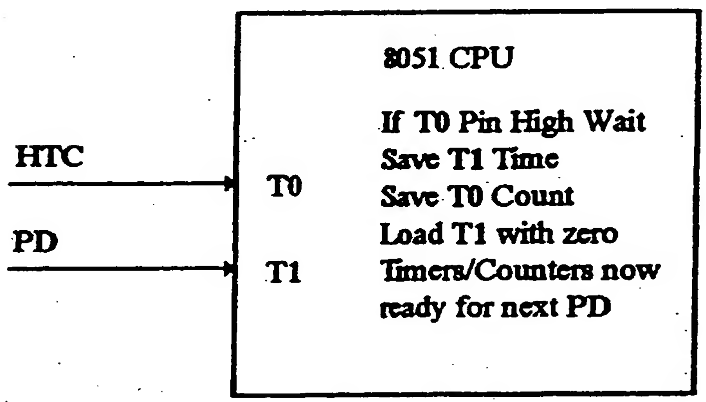

8051 CPU
HTC
PD
T0
T1
If T0 Pin High Wait
Save T1 Time
Save T0 Count
Load T1 with zero
Timers/Counters now
ready for next PD

Fig. 8

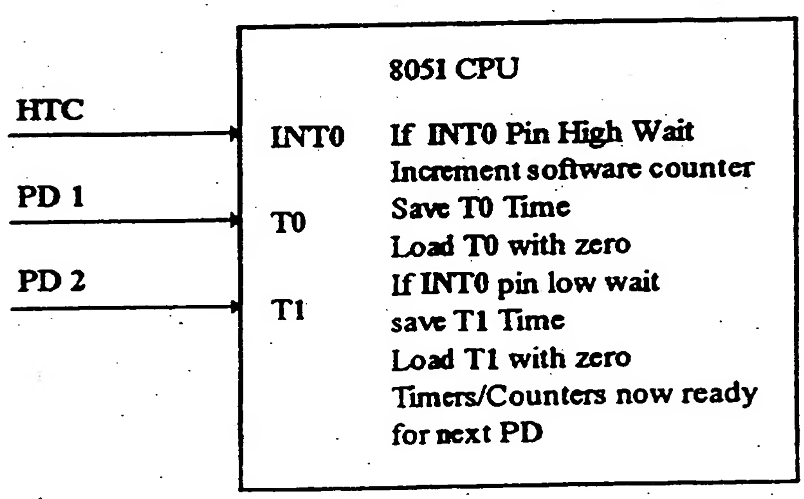

8051 CPU
HTC
PD 1
PD 2
INT0
T0
T1
If INT0 Pin High Wait
Increment software counter
Save T0 Time
Load T0 with zero
If INT0 pin low wait
save T1 Time
Load T1 with zero
Timers/Counters now ready
for next PD

Fig. 9

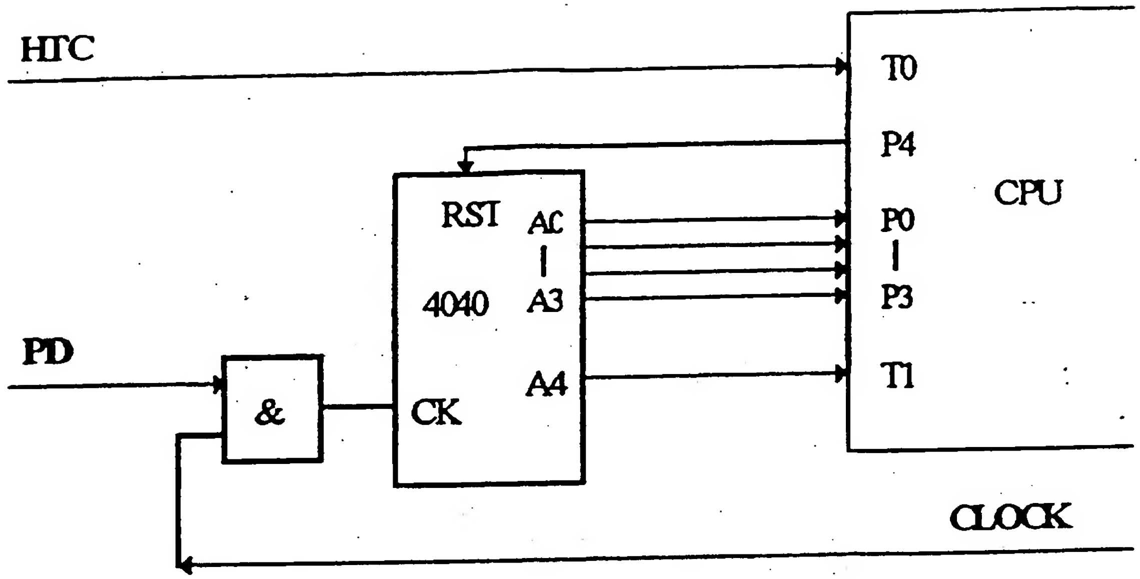

HTC
T0
P4
CPU
RST
AC
4040
A3
P0
P3
PD
&
A4
T1
CK
CLOCK

Fig. 10

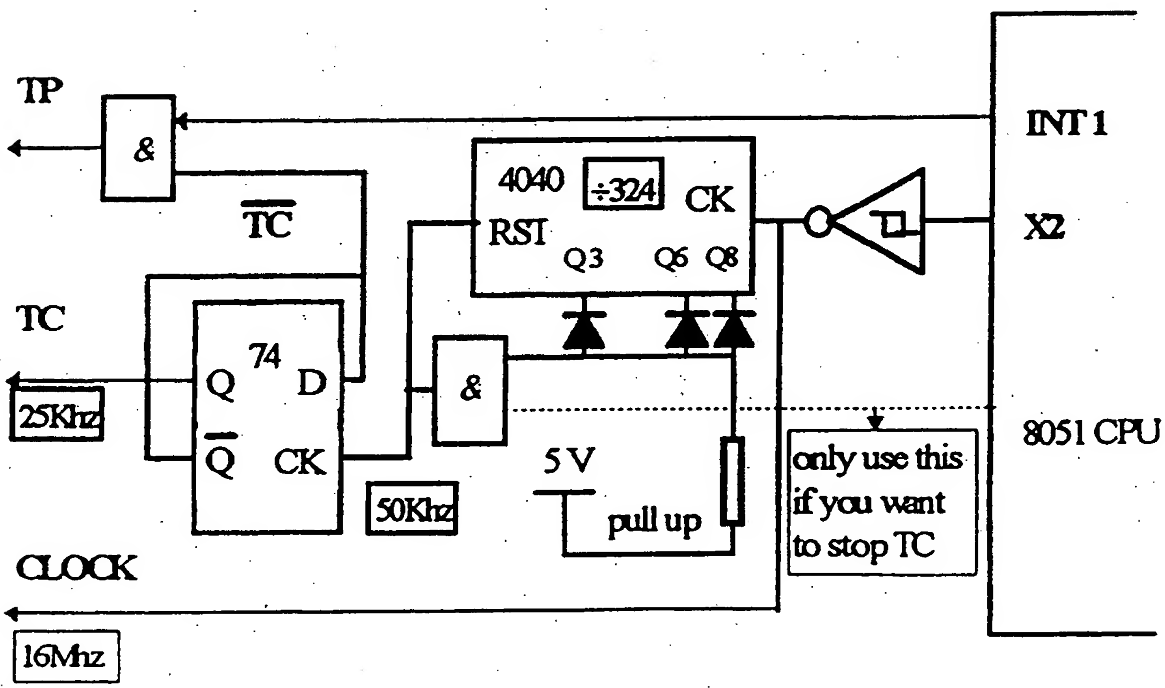

TP
&
INT1
4040
÷324
CK
TC
RST
X2
Q3
Q6
Q8
TC
74
Q
D
&
25Khz
8051 CPU
Q
CK
5 V
only use this if you want to stop TC
50Khz
pull up
CLOCK
16Mhz

Fig. 11

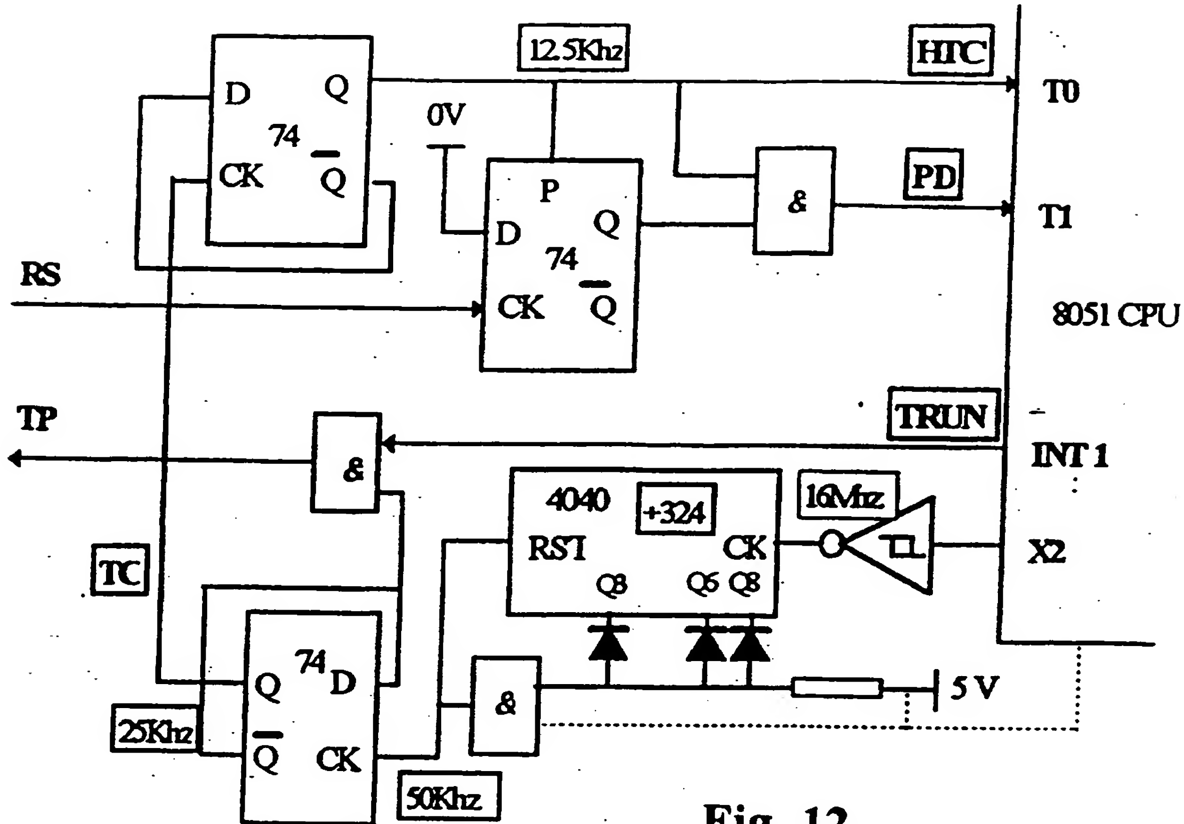

12.5Khz
HTC
D
Q
74
CK
Q
0V
P
D
Q
74
CK
Q
&
PD
T0
T1
RS
8051 CPU
TP
&
TRUN
INT 1
4040
+324
16Mhz
RST
CK
Q3
Q6 Q8
TTL
X2
TC
74
Q
D
&
5 V
25Khz
Q
CK
50Khz

Fig. 12

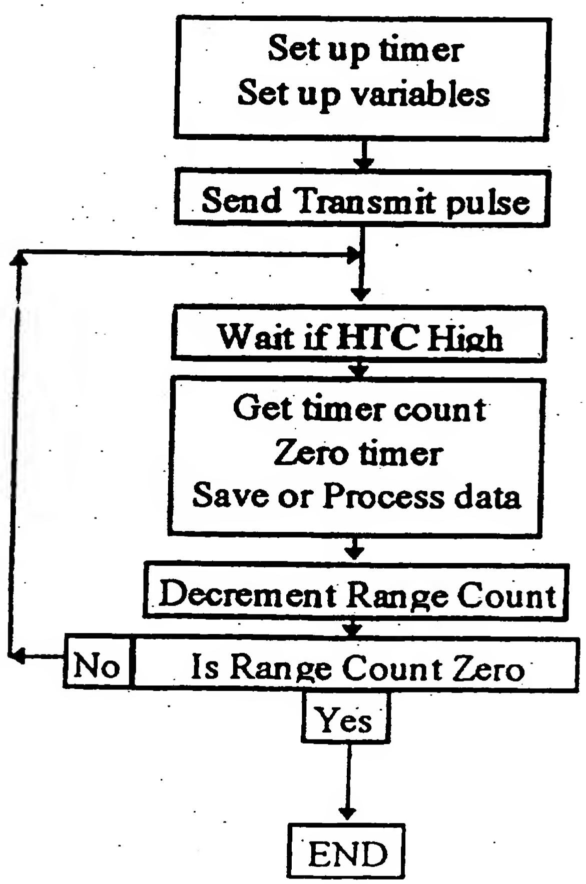

Set up timer
Set up variables
Send Transmit pulse
Wait if HTC High
Get timer count
Zero timer
Save or Process data
Decrement Range Count
No
Is Range Count Zero
Yes
END

Fig. 13

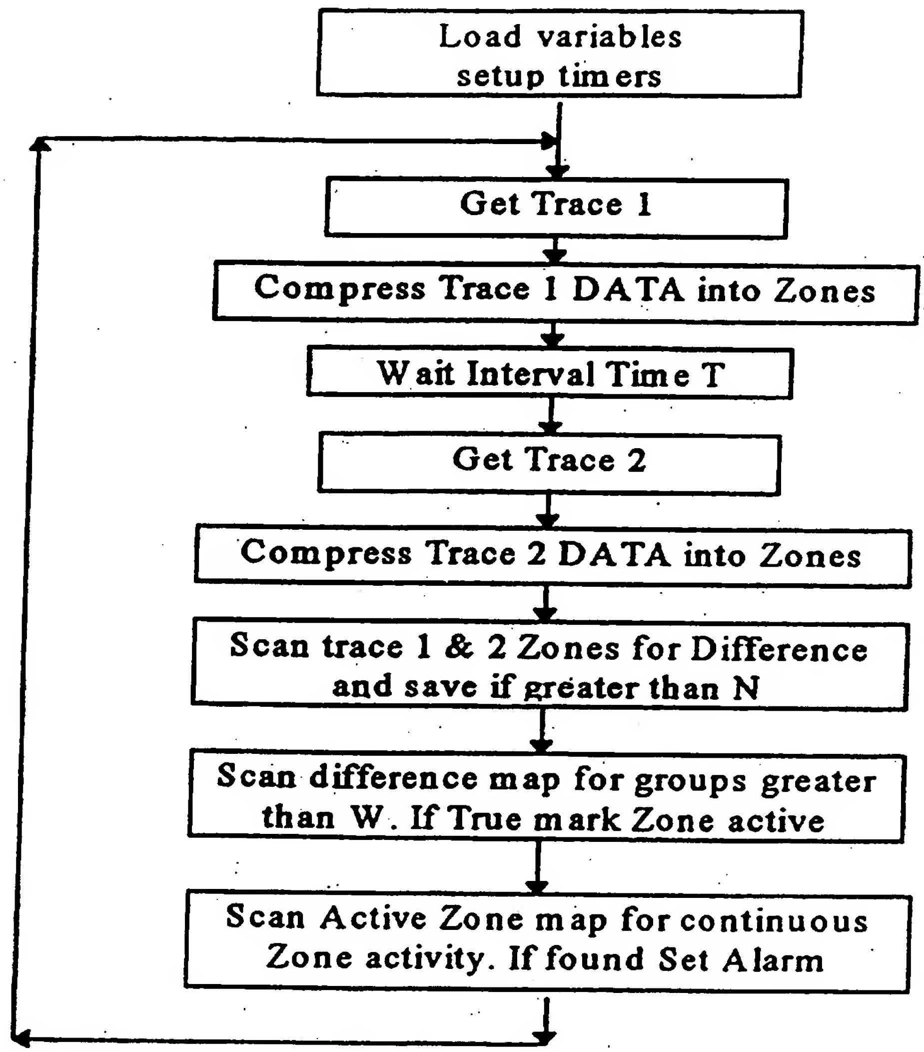

Load variables
setup timers
Get Trace 1
Compress Trace 1 DATA into Zones
Wait Interval Time T
Get Trace 2
Compress Trace 2 DATA into Zones
Scan trace 1 & 2 Zones for Difference and save if greater than N
Scan difference map for groups greater than W. If True mark Zone active
Scan Active Zone map for continuous Zone activity. If found Set Alarm

Fig. 14

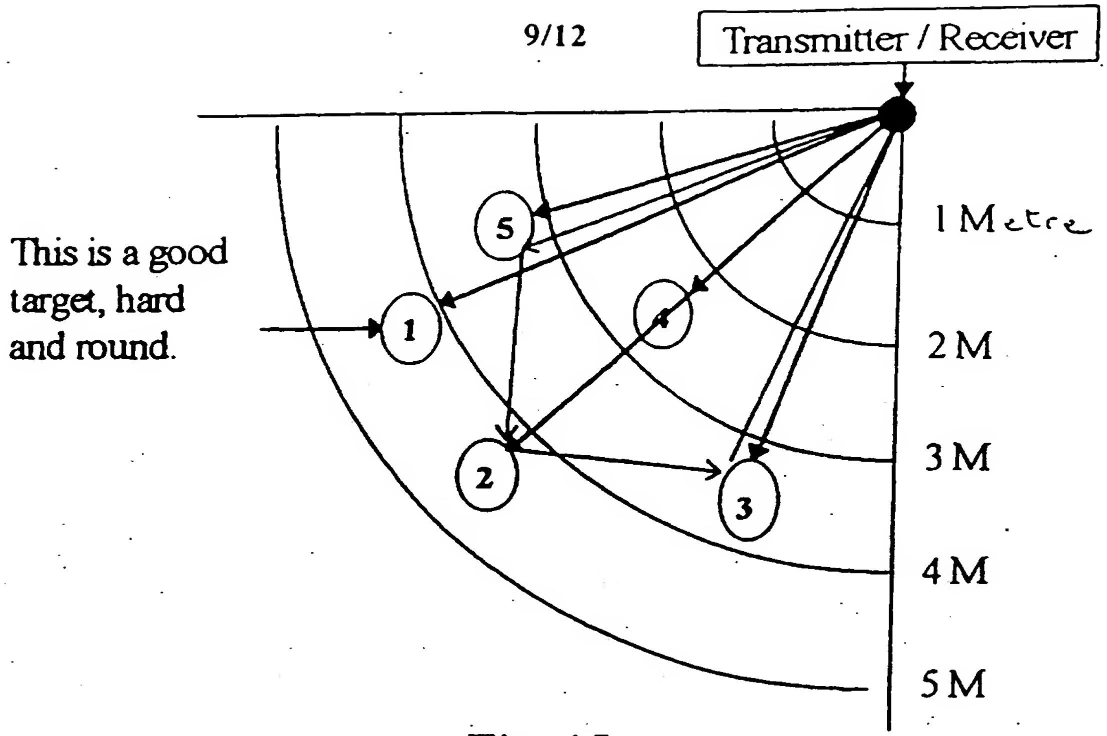

Transmitter / Receiver
This is a good target, hard and round.
1
2
3
4
5
1 Metre
2 M
3 M
4 M
5 M

Fig. 15

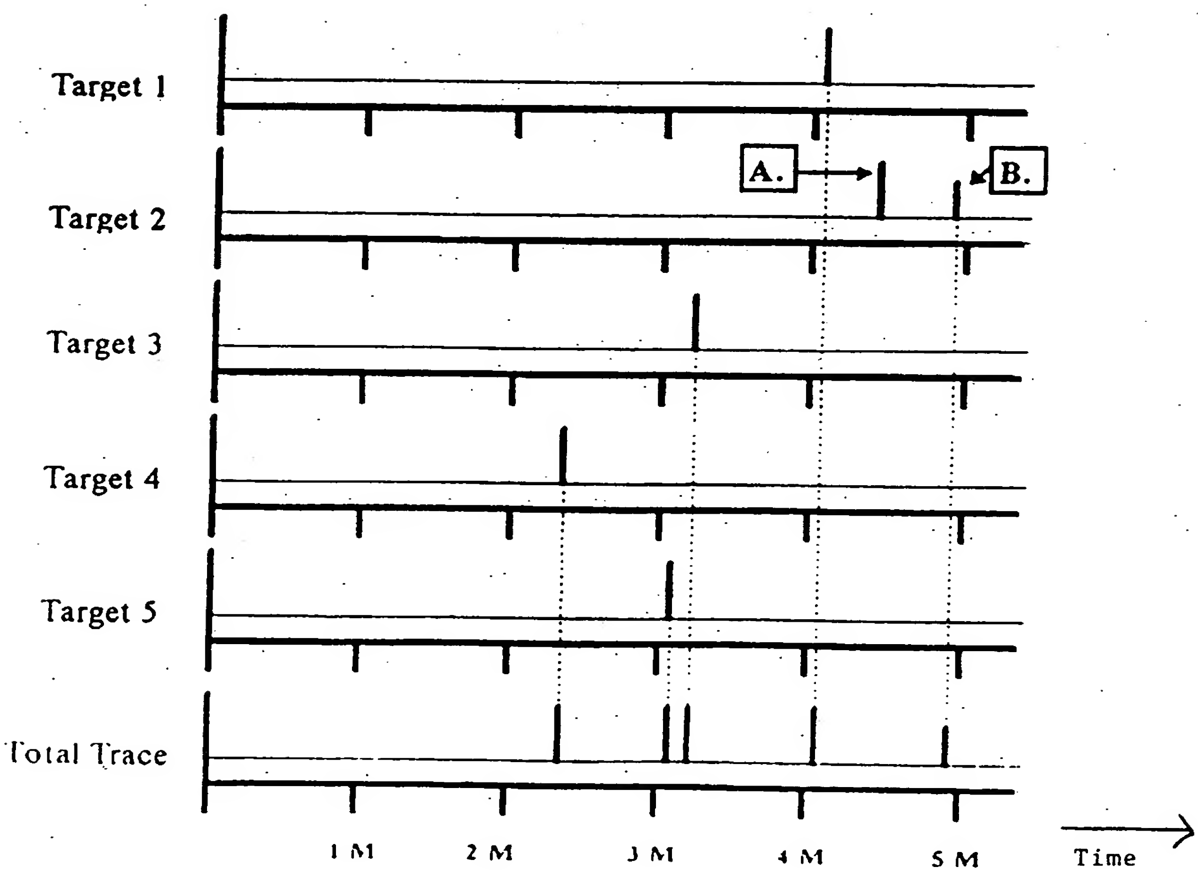

Target 1
Target 2
Target 3
Target 4
Target 5
Total Trace
A.
B.
1 M
2 M
3 M
4 M
5 M
Time

Fig. 16

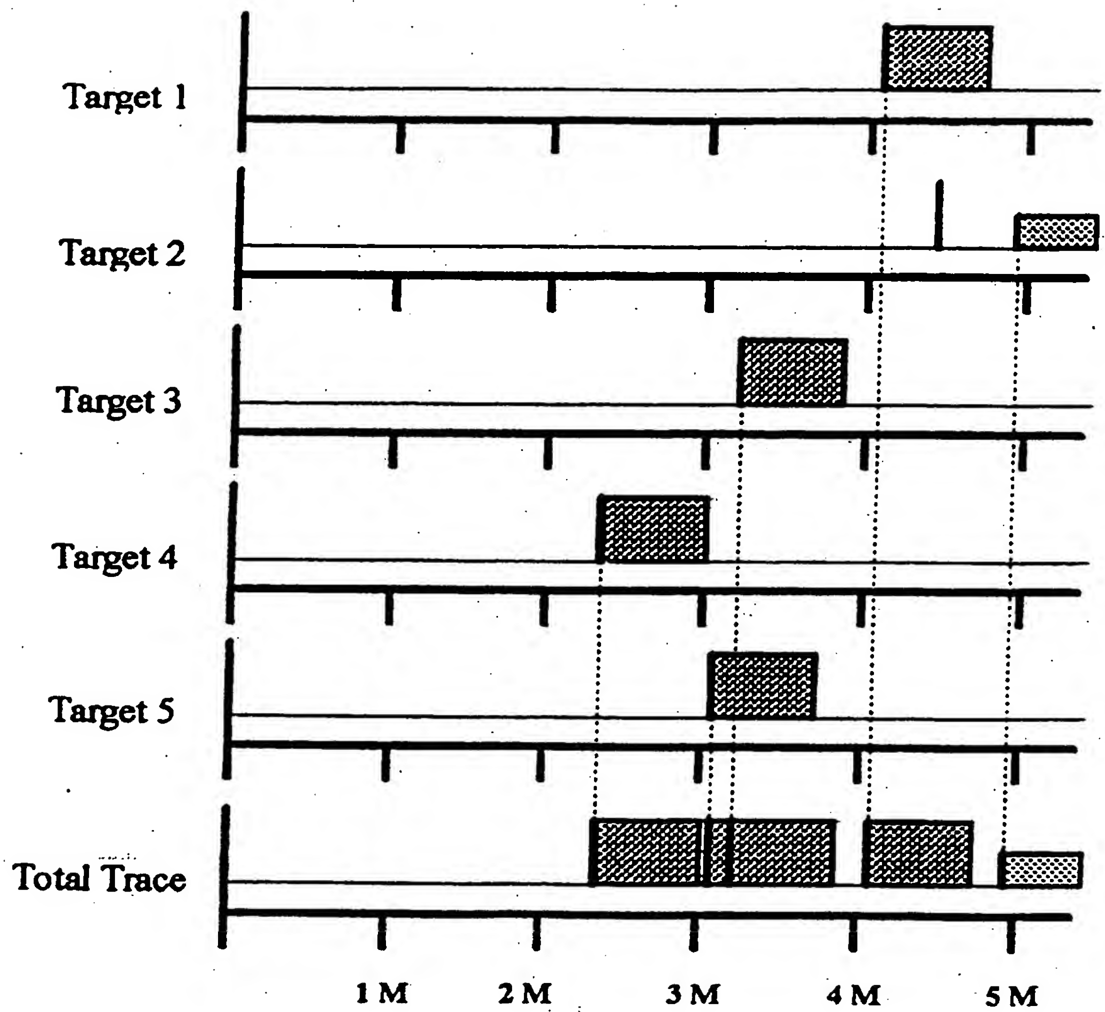

Target 1
Target 2
Target 3
Target 4
Target 5
Total Trace
1 M
2 M
3 M
4 M
5 M

Fig. 17

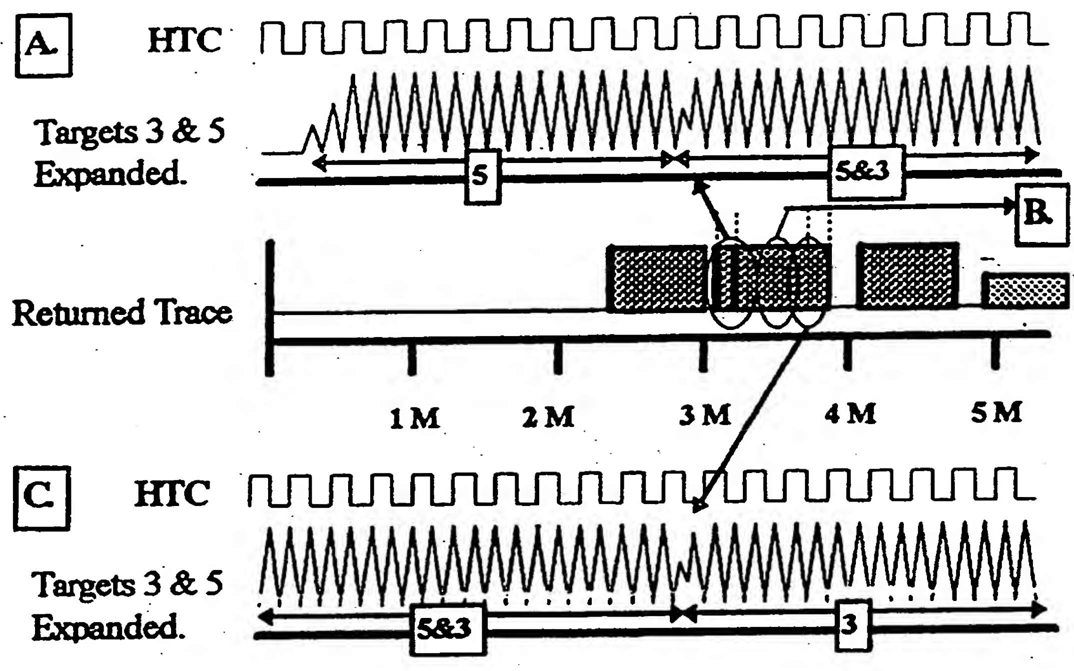


Fig. 18(a)

A.	3C 3C 3C 3C 3C 2B 4F 5A 5A 5A 5A 5A
B.	5A 5A 5A 5A 5A 5A 5A 5A 5A 5A 5A 5A
C.	5A 5A 5A 5A 5A 32 18 1E 1E 1E 1E 1E

This example is not actual DATA

Fig. 18(b)

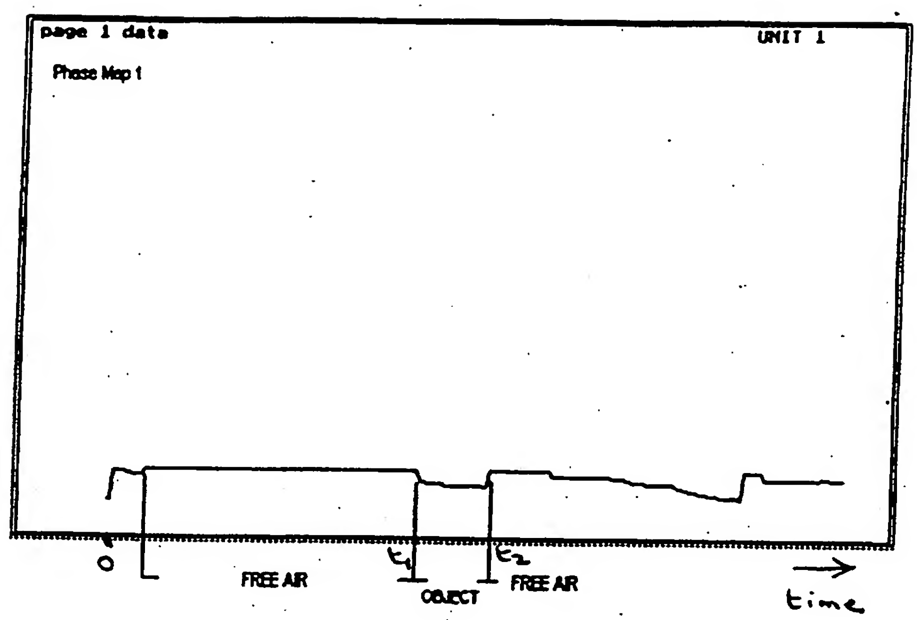

page 1 data
UNIT 1
Phase Map 1
0
t_1
t_2
FREE AIR
OBJECT
FREE AIR
time

Fig. 19

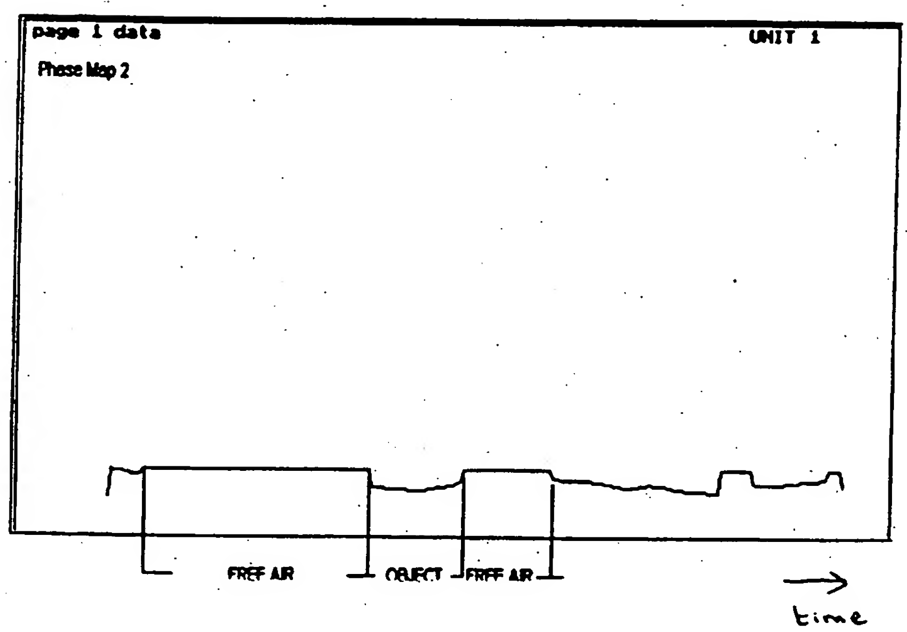

page 1 data
UNIT 1
Phase Map 2
FREE AIR
OBJECT
FREE AIR
time

Fig. 20

2299405

ULTRASONIC MONITOR

This invention relates to ultrasonic monitors, and particularly to an ultrasonic security monitor adapted to provide an alarm signal in the event of an unwanted event occurring in the field of view of the monitor.

The unwanted event may for example be the removal of an object from the field of view, or the appearance of a new object in the field of view.

This invention relates to inventive modifications and improvements of the ultrasonic monitors disclosed in prior patent specification no. W094/20021 (application no. PCT/GB94/00343), and the disclosure of that specification is considered to be incorporated herein.

In the prior specification there is disclosed a movement monitor for monitoring the movement of an object comprising an ultrasound emitter, an ultrasound receiver adapted to receive sound waves reflected from the object, pulse energisation means for causing the emitter periodically to emit a burst of ultrasound pulses, and detection means responsive to the receiver to monitor the output of the receiver and to indicate an abnormal movement or lack of movement.

In the prior specification there is further disclosed an ultrasonic monitor as set forth in the preceding paragraph in which the detection means is arranged to identify particular objects in the field of view of the receiver by analysing the sequence of phase difference signals pulse by pulse and by identifying correlated relationships within groups of pulses, and to memorise characteristics of the echo signal, and during subsequent monitoring to discriminate between various echo signals, whereby an

indication signal indicative of an abnormal movement or lack of movement is generated only in response to the condition of a particular selected object.

There is further disclosed in the prior specification an ultrasonic monitor having a training sequence which comprises causing the emitter to emit 'bursts' of ultrasound pulses, the bursts having different durations, and monitoring the durations of the resulting echoes received from different objects, the change in duration of an identifiable echo corresponding to a particular object with the change in duration of the emitter pulse being monitored, in order to establish a memory profile of that object, memory profiles being established in this way for each of the objects in the field of view of the receiver that receive ultrasonic emissions.

There is further disclosed in the prior specification an ultrasonic monitor in which the monitor has a normal operation following the training sequence in which the echoes from objects other than the particular object to be monitored are disregarded, and an alarm signal is generated only in response to an abnormal condition being detected in the movement or lack of movement of the particular object.

One application of the present invention is to an intruder alarm particularly, but not exclusively, to an alarm for responding to the approach of an intruder to a baby and/or to the removal of the baby from a cot, incubator or the like. Tagging systems have been proposed to deal with the problem of the unauthorised removal of a baby from a hospital ward, but such systems are expensive and require the baby to wear an unsightly tag.

According to one aspect of the present invention an ultrasonic monitor for monitoring the security of an object, hereinafter referred to as the 'monitored object', comprises:

a) an ultrasound emitter adapted to emit ultrasound into a region in which the monitored object is located in use, and an ultrasound receiver adapted to receive sound waves reflected from the monitored object,

b) pulse energisation means for causing the emitter periodically to emit a burst of ultrasound oscillations,

c) detection means responsive to the receiver to monitor the output of the receiver and to measure the phase of received ultrasonic waves relative to the phase of the emitted waves to provide phase difference signals, and wherein the detection means is arranged to discriminate between said monitored object and other objects in the field of view of the receiver by analysing the sequence of said phase difference signals pulse by pulse (these pulses are the individual oscillations, ie wave cycles of the received ultrasonic signals), and by identifying correlated relationships within groups of said pulses, and to memorise those relationships as representing respectively the different objects in the field of view, and wherein

d) the detection means during a subsequent monitoring cycle is arranged to compare relationships of the phase difference signals with the said memorised relationships so as to identify intrusion into said field of view of a new object, and being arranged to produce an alarm signal on detection of the intrusion of said new object.

Preferably the detection means comprises a new object discriminating means which is adapted to inhibit the production of an alarm signal in response to the intrusion of a new object of a predetermined range of characteristics.

For example, the predetermined range of characteristic could be a range of dimensions of the new object, whereby an alarm signal is only generated by the intrusion of certain sizes of new object into the field of view.

When the first aspect of the invention is applied to the monitoring of a baby, or to the security of a valuable artefact, the detection means can be trained or pre-set to respond to the introduction of a hand or implement into the field of view to initiate an alarm signal.

Alternatively, or in addition, the detection means may be trained or pre-set to initiate an alarm signal when the monitored object is removed from the field of view of the receiver, by detecting that the monitored object is no longer in the field of view and/or by detecting the movement required to remove the monitored object from the field of view.

In the foregoing prior specification, one important use of the monitor is to monitor the breathing or other regular movement of a baby. According to a preferable feature in accordance with the first aspect of the present invention, the monitor is adapted to monitor the breathing of the baby in addition to detecting the presence of an intruder and/or removal of the baby from the field of view of the receiver. All these functions can be performed by the detection means by suitable analysis of the signals received by the receiver.

The alarm signal produced can be arranged to be different as between detection of an intruder into the field of view and removal of the monitored object from the field of view.

Preferably a key or code-operated disabling means is provided to enable the detection means, or at least the alarm function, to be disabled for authorised attention to the monitored object.

The detection means may be arranged in appropriate circumstances to disregard movement of the monitored object within the field of view, and provided that the monitored object remains within the field of view. For example, when monitoring the security of a baby, movement of the baby within the confines of the cot could be disregarded, and this adaptive behaviour of the discrimination means can be important.

Since the memorising and discriminating functions of the detection means will usually be implemented by software it is possible in appropriate cases to train one detection means, and then to replicate the trained software in other monitors.

A further, important application of the present invention is to a security system for detecting the presence of an intruder in a building or in an outside location such as the garden of a private property, hereinafter referred to as the 'monitored zone'.

At the present time Passive Infra Red (PIR) detectors are widely used for this purpose. They are arranged to respond to a sudden change of temperature in the viewing field to indicate the appearance of an intruder in the viewing field. Unfortunately such detectors are prone to respond to

events other than a human intruder, for example an alarm signal can be generated by a moth flying through the field of view and relatively close to the detector.

According to a second aspect of the present invention an ultrasonic monitor for detecting an intruder in a monitored zone comprises:

a) an ultrasound emitter adapted to emit ultrasound into the monitored zone, and an ultrasound receiver adapted to receive sound waves reflected from objects in the monitored zone,

b) pulse energisation means for causing the emitter periodically to emit a burst of ultrasound oscillations,

c) detection means responsive to the receiver to monitor the output of the receiver and to measure the phase of received ultrasonic waves relative to the phase of the emitted waves to provide phase difference signals, and wherein the detection means is arranged to discriminate between various objects in the field of view of the receiver by analysing the sequence of said phase difference signals pulse by pulse (these pulses are the individual oscillations, ie wave cycles of the received ultrasonic signals), and by identifying correlated relationships within groups of said pulses, and to memorise those relationships as representing respectively the different objects in the field of view, and wherein

d) the detection means during a subsequent monitoring cycle being arranged to compare relationships of the phase difference signals with said memorised relationships so as to identify intrusion into said field

of view of a new object, and being arranged to produce an alarm signal on detection of the intrusion of said new object.

As with the first aspect of the invention, the detection means preferably comprises said new object discrimination means.

When an ultrasonic monitor in accordance with the second aspect of the invention, and comprising said new object discriminating means, is applied to monitor a room or an outside location, the new object discriminating means is preferably arranged to produce an alarm signal only in response to the appearance of an object of the size of a human being into the field of view.

The inventive monitor is capable of distinguishing between small objects close to the receiver and large objects remote from the receiver, so the incidences of false alarms can be much reduced as compared with PIR detectors. The monitor assesses the distance of an object from the transmitter and receiver by measuring the time delay between transmissions of a burst of ultrasonic pulses and receipt of the reflected ultrasound pulses, rather than using the phase information concerning the phases of the individual pulses themselves.

The velocity of movement of the new object through the field of view may also be used by the new object discriminating means as a distinguishing characteristic. This can help to avoid false alarms caused by, for example, a shadow of a fixed object which passes through the field of view during the course of a day.

The new object discriminating means may be pre-programmed to ignore well-known false movements so as to cut out recurring false alarm situations. This pre-programming may be accomplished either by subjecting a detection means to the movement situation which provides a false alarm, and then setting parameters of the new object discriminating means based on the receiver signals actually produced by the movement situation, or the type of signals predicted to result from a false alarm movement situation may be calculated and the new object discriminating means may be manually set or pre-adjusted to ignore such false alarm movement situations by ignoring an occurrence of the calculated type of signal.

When the inventive monitor is used to monitor a room or outside location, the alarm signal is preferably a radio telephone signal. This avoids reliance on land-line telephones, which are commonly cut by prospective intruders.

An advantage of a monitor in accordance with the second aspect of the invention is that the discrimination means is adaptive to any changes which may have taken place in the monitored zone, for example furniture being moved in a room, since the previous period of use, because the monitor can be arranged to enter the surveying mode each time the monitor is brought into use.

It is possible to use a monitor in accordance with the second aspect of the invention to provide a fire alarm facility, by utilising the feature that in the event of a fire the velocity of ultrasonic waves through hot air is affected, and the apparent overall shift of the objects in the field of view can be detected by the detection means.

According to a third aspect of the invention an ultrasonic monitor for detecting an over-temperature situation in a monitored zone comprises:

a) an ultrasound emitter adapted to emit ultrasound into the monitored zone, and an ultrasound receiver adapted to receive sound waves reflected from objects in the monitored zone,

b) pulse energisation means for causing the emitter to emit a burst of ultrasonic oscillations (each burst of ultrasound comprises a plurality of oscillations),

c) detection means responsive to the receiver to monitor the output of the receiver, the detection means being arranged to determine the phase of the individual ultrasonic oscillations in the reflected waves received by the receiver, the phase being measured relative to the phase of the oscillations transmitted, and for a cycle of operation of the emitter in which one burst of ultrasonic oscillations is emitted, and the reflected waves received by the receiver are examined, the detection means records against time in the cycle the phases of the individual received pulses, so as to produce a phase-time profile (or database) for that cycle, and to the detection means being arranged to compare the phase-time profile of a later cycle with the phase-time profile of one or more earlier cycles and to produce an alarm signal in response to an overall time shift of the phase-time profile greater than a predetermined time shift.

The predetermined time shift is set to correspond to a predetermined excessive rise in temperature associated with a fire itself or with smoke.

Thus an ultrasonic monitor in accordance with the third aspect of the invention can be used either as a fire detector and/or as a smoke detector.

According to a fourth aspect of the invention an ultrasonic monitor for detecting unauthorised movement of an object in a monitored zone comprises:

a) an ultrasound emitter adapted to emit ultrasound into the monitored zone, and an ultrasound receiver adapted to receive sound waves reflected from objects in the monitored zone,

b) pulse energisation means for causing the emitter to emit a burst of ultrasonic oscillations (each burst of ultrasound comprises a plurality of oscillations),

c) detection means responsive to the receiver to monitor the output of the receiver, the detection means being arranged to determine the phase of the individual ultrasonic oscillations in the reflected waves received by the receiver, the phase being measured relative to the phase of the oscillations transmitted, and for a cycle of operation of the emitter in which one burst of ultrasonic oscillations is emitted and the reflected waves received by the receiver are examined, the detection means records against time in the cycle the phases of the individual received pulses, so as to produce a phase-time profile (or database) for that cycle, and the detection means being arranged to compare the phase-time profile of a later cycle with the phase-time profile of one or more earlier cycles and to produce an alarm signal in response to a difference between phase-time profiles which exceeds a predetermined difference.

The alarm signal can take any convenient form, such as a signal to a remote listening centre.

The unauthorised movement may comprise movement of an existing object in the monitored zone, or be the movement of a new object into the zone. In the latter case said predetermined difference is the previously mentioned new object discrimination means.

In a security application of the invention the unauthorised movement to be detected may be removal of the object from the zone and/or it may be introduction of a new object of predetermined characteristics, such as an intruder or a vehicle, into the monitored zone.

The phase-time profiles that are compared may be those of a current cycle and a plurality of earlier cycles, or they may be the phase-time profile of successive cycles.

An ultrasonic security monitor in accordance with the invention, and various modifications in accordance with the invention, will now be described, by way of example only, with reference to the accompanying schematic drawings in which:

Figure 1 is a block circuit diagram of the ultrasonic security monitor,

Figure 2 is a circuit diagram of a first (single channel) form of digital phase difference detector for use in the monitor of Figure 1,

Figure 3 is a pulse diagram showing the pulse trains at various locations in the circuit of Figure 2, in particular a phase difference signal PD,

Figure 4 is a circuit diagram of a dual channel, second form of digital phase difference detector for use in the monitor of Figure 1,

Figure 5 is a pulse diagram showing pulse trains in the circuit of Figure 4, in particular two phase difference signals PD1 and PD2,

Figure 6 is a circuit diagram of a dual channel, third form of digital phase difference detector for use with two ultrasonic receivers,

Figure 7 is a pulse diagram relating to Figure 6,

Figure 8 is a diagram of the timer functions in the microprocessor when used with the DPDD of Figure 2,

Figure 9 is a diagram of the timer function in the microprocessor when used with the DPDD of Figure 4,

Figure 10 is a block diagram of circuitry for increasing the resolution of the phase difference measuring means,

Figure 11 is a block diagram of pulse generating circuitry for the 25Khz ultrasonic pulse transmitter,

Figure 12 is a block diagram of pulse generating and pulse receiving circuitry of a low resolution 25Khz every other cycle CCT in accordance with the invention,

Figure 13 is a software flow diagram for reading the single channel DPDD of Figure 2,

Figure 14 is a software flow diagram for analysing trace zones of the phase traces of successive cycles of operation of a movement detector in accordance with the invention,

Figure 15 is a schematic view of the layout of fine targets positioned for discussion purposes relative to a transmitter and receiver unit,

Figure 16 shows various short pulses reflected from the targets of Figure 15,

Figure 17 is similar to Figure 16 but showing the theoretical result of using a relatively long transmission pulse in the schematic arrangement of Figure 15,

Figure 18 shows in 18(a) the fine structure in the received pulses of Figure 17, and in 18(b) stored phase data corresponding to the theoretical trace of 18(a),

Figure 19 shows a typical phase trace of a single cycle of a movement detector in accordance with the invention, and

Figure 20 shows a phase trace subsequent to that of Figure 19.

The use of ultrasound to identify objects in the field of view of an ultrasonic transmitter and receiver is described in detail in specification no. WO94/20021 and reference should be made to that specification for an understanding of how the phases of received signals relative to transmitted signals are used to build up a picture of the monitored objects. However,

some aspects of this are described hereinafter under the heading 'basic theory of target recognition'.

For convenience, Figure 1 of WO94/20021 has been repeated here as Figure 1 since it shows a block diagram of a system which can be implemented so as to operate in accordance with the present invention. The ultrasonic transmitter 1 is caused to emit a pulse of ultrasonic vibrations, that is, a burst of vibrations constituting a single pulse.

Three forms of the digital phase difference detector 8 of Figure 1 will now be described, with reference to the accompanying Figures 2 to 7.

Figure 2 shows a basic digital phase difference detector (DPDD) sampling every other cycle. The basic DPDD consists of a D type flip flop with the Data pin **D** tied to zero Volts and the Pre-set pin **P** tied to a half transmit clock **HTC**. The output from the ultrasonic receiver **RS** is tied to the clock input. The **Q** output is **&** with the **HTC** producing a pulse width proportional to the phase difference **PD** between transmitted clock **TC** and received signal **RS** (Figure 3). When **HTC** is low the **Q** output is high, the D type is disabled and **PD** is low. When **HTC** is high the D type is enabled and **PD** goes high, a rising edge on **RS** clocks a zero through the D type and **PD** goes low.

With reference to Figure 4, this shows a dual channel DPDD sampling every cycle. The DPDD is shown producing a **PD** pulse for each received cycle. The state of **HTC** indicates which **PD** is valid (sampling finished), when high **PD 2** is valid, when low **PD 1** is valid (see Figure 5).

Whereas the circuits of Figures 2 and 4 are for use with a single ultrasonic receiver, the circuit of Figure 6 is for use with two ultrasonic receivers. The circuit of Figure 6 provides dual channel DPDD sampling every other cycle in stereo. The operation of the circuit of Figure 6 is as the dual channel DPDD of Figure 4 but with two inputs. Figure 7 shows the pulses in this circuit.

It will be appreciated that combinations of the circuits of Figures 4 and 6 can be used to achieve more than two channels of PD signals if desired.

Figures 8 and 9 relate to interfacing the DPDD with a 8051 CPU for the single channel and dual channel cases respectively.

As we can see in Figure 3 **PD** pulse width is proportional to the phase shift, and if we take this output and feed it into a CPU with timers/counters we can use this signal to start and stop a timer **T1**. By sampling **HTC** we can tell when that timer is frozen. If we feed **HTC** into a counter **T0** we have the time taken for that wave front, from these two counters we can calculate the distance. The **Resolution** is limited to the maximum speed the CPU timer can run

$$\text{resolution} = \frac{\text{Speed of Sound}}{2 \times \text{Timer rate}}$$

Tl must be configured as a Timer started by a High on **T1** pin and **T0** as a Counter.

With reference to Figure 9, for dual channel, **T0** and **T1** must both be configured as timers started by a High on their pins and **INT0** as an input.

Improving the resolution of a single channel DPDD.

As we can see the CPU limits resolution. To increase resolution we can add a counter and provide port pins for the extra bits (data and control). Figure 10 shows if we & PD with an external clock CLOCK, feed the output into the clock input of the 4040 and wait for HTC to go low we can increase the resolution by 16. In this case TI must be configured as a counter and not a timer. The Lsbs 0-3 are on P0-P3, bit 4 is on T1, and the counter T1 holds bits 5 upwards. When all of the bits are read and before HTC goes high P4 must go high to reset the 4040 and then low to enable it.

Generating the Control Signals

For Stability reasons it is best to generate the transmit frequency from the CPU clock. This is done by dividing the clock by 324 producing a 50Khz pulse and feeding it into a divide by two, to produce a 25Khz Square wave TC, and this runs continuously. The transmit pulse TP is the gated output of TC & INTI. When INTI is High TP = TC and when Low TP = 0. TC is always Low after HTC has changed state, so if the transducer is turned on and off at this point it guarantees a clean whole cycle pulse. If the transmit pulse were not to be clean, phase noise would be produced. The CLOCK output is for the High Resolution DPDD.

As a machine cycle is Clock ÷ 12, 16Mhz ÷ (12 x 12.5Khz) will not produce an integer. It is necessary to produce an integer to stop digital drift. In Figure 13 the integer produced for the wave length of HTC is 108 M/cs exactly, meaning HTC is in synchronisation with the CPU machine cycles thereby eliminating any digital drift. This gives HTC a frequency 12.345Khz and a transmit frequency of 24.691Khz. See the following table 1:

Table 1

HTC Machine cycles	$\frac{\text{CPU Clock}}{12 \times \text{HTC Frequency}}$
HTC Frequency	$\frac{\text{CPU Clock}}{12 \times \text{HTC Machine Cycles}}$
TC Frequency	$\frac{\text{CPU Clock}}{6 \times \text{HTC Machine cycles}}$
Divide by N (4040)	3 x HTC Machine Cycles

SOFTWARE TO PROVIDE PHASE DATA

All of the examples in this section are for an 8051 CPU.

Reading a Single Channel Low Resolution DPDD.

The basic flow diagram for a single channel DPDD is shown in Figure 16. The first step is to set up the timer/counters. Then load the variables with the number of cycles to be read and the transmit pulse length. Once the transmit pulse has been sent you will be waiting for **HTC** to go low, when this happens the timer will have the **PD** pulse width in timer counts. This count will from now on be referred to as DATA. What you do with this DATA is limited by the time until the next **HTC** low. As **HTC** frequency is a constant, the amount of machine cycles between **HTC** lows can be calculated (see Table 1). For the 8051 it is as follows:

$$\text{Maximum number of Machine Cycles} = \frac{\text{CPU Clock}}{12 \times \textbf{HTC}\ \text{Hz}}$$

The following example shows how to read an 8 bit single channel DPDD. For CCT see Figure 14.

Example 1. Every other cycle.

HTC = 12.345Khz Clock = 16Mhz Total M/c = 108

First we must set-up T1 as a timer and T0 as a counter.

```
MOV     TH0,zero
MOV     TL0,zero        Timer 0 will count HTC cycles
MOV     TMOD,Timer/Counter mode
```

Then load the address pointer if the data is to be saved.

```
MOV     DPTR,External Memory Start address
```

The number of HTC cycles we will sample.

```
MOV     R2,Number of HTC cycles to be read
```

The length of the transmit pulse in HTC cycles

```
MOV     A,Transmit pulse width
```

Turn on transmitter, wait until pulse is complete and turn of.

```
JNB     T0,$    (2 M/c) Waiting for HTC High
JB      T0,$    (2 M/s) Waiting for HTC Low
SETB    TRUN            Turn Transmitter on
CJNE    A,TL0,$         Jump if Pulse not complete
CLR     TRUN            Turn Transmitter off
```

Zero Timer 1and turn it on

```
MOV     TL1,Zero
MOV     TH1,Zero
SETB    TCON.6          Turn on Timer 1
```

Now that the Transmit pulse has been sent we wait for a clean **HTC** edge to start collecting data. The first timer reading will be an error but every one after that will be correct.

```
DATALOOP:
        JNB     T0,$      (2 M/c) Waiting for HTC High
        JB      T0,$      (2 M/s) Waiting for HTC Low
```

As **T0** pin is low, **T1** has frozen,, so we now read and zero the timer **T1**.

```
        CLR     A         (1 M/c) Zero Accumulator
        XCH     A,TLI     (1 M/c) Get T1 byte and zero TL1
        MOVX    @DPTR,A
        INC     DPTR
```

Jump if we haven't finished to get the next DATA byte

```
        DJNZ        R2,DATALOOP (2 M/c) Total M/c = 12 + 2
        CLR         TCON.6        Turn Timer 1 off
```

Processing the Phase Data

Up to now only the Hardware and Software to run it have been described. The purpose of the DPDD is to collect phase data. There are two ways in which we can deal with the collected phase data:

Method 1. Compare the overall phase trace of each cycle with the phase trace of the cycle before it. This is the quickest way but with limited noise rejection.

Method 2. Scan the phase trace, and group portions of the phase trace that have common characteristics with their neighbouring portions of that trace,

and compare those groups to the groups of the phase trace of the preceding cycle. This is the cleanest way but has a large code time overhead.

By 'cycle' we mean here the transmission of one pulse of ultrasound (which pulse will be made up of a plurality of ultrasound vibration cycles) and the analysis of the resulting signals received by the receiver.

A Basic Movement Detector Operated in Accordance with Method 1

A detector was constructed which compressed its trace from 1280 Data bytes into 80 bytes which we shall call 'trace zones'. A Compressed Byte was 16 DATA Bytes added together and divided by 16. This had the effect of:

1. Hiding small movement within part of that 16 byte trace.
2. Passing small movement if the whole 16 byte trace was moving
3. Allowing large single cycle phase change (noise) to pass
4. Allowing multi-directional phase change to pass as single directional change.

Figure 14 shows a basic flow diagram for this detector. T = Time interval between samples say 0.1 of a second. N = Maximum phase difference allowed between trace 1 zone and the corresponding zone of trace 2. W = Minimum number of consecutive zones showing difference before the zone is marked active.

These trace zones resulting from the foregoing compression procedure were compared with the corresponding trace zones of the immediately preceding trace. If the difference was greater than n then that difference would be saved. If its neighbours had a difference too then that zone would be considered active.

Now this method appears solid in principle but it suffers a number of drawbacks for dealing with noise.

Improved Movement Detector Operating in Accordance with Method 2

Method 2 involves making a list of groups with common characteristics (see basic theory) and comparing trace 1 list and trace 2 list for group movements with purpose.

A target may or may not reflect sound, but there is one thing a target always does and that is it blocks sound from things behind it. So if it doesn't reflect sound its path can be shown by what it breaks up behind it. This means if we scan our list from distance zero up, when we find a group with purpose it may be followed by groups with no purpose. The larger the first group the more broken up will be the groups behind. This is truer for targets directly in front of the receiver, but not so true for targets at the edges. So our software should take all this into account and still run at an acceptable sample time. This is a drawback of this method, but we can deal with noise in a more intelligent way.

We can say anything that does not comply with definition of a target is noise, anything close to that is a bad target and only a good target good and stationary for T long becomes a solid target. This gives us more than one thing to look for.

1. A good target moving with purpose for D distance or T time.
2. A solid target breaking up for T time.
3. A good or solid target moving back and forth (drafts and vibration).
4. The general condition of the trace (noise, bad and good ratios).

Plus we can test the target area (varying the transmit pulse length).

Basic Theory of Target Recognition

The following terms will now be defined:

First order waves

These waves carry the characteristics of the transmitting device. They are only changed by the substance through which they propagate. The time taken and the natural decay in energy and frequency can be calculated by knowing the characteristics of that substance.

Second order waves

These are first order waves with the characteristics of one target added to them.

Third and higher order waves

These waves have the characteristics of two or more targets added to them and can be unusable without complex algorithms to filter them.

Minimum Phase Shift

This is the minimum phase shift detectable by the DPDD. See Table 2.

Resolution

This is the minimum distance that the DPDD can detect. See Table 2.

Lets start with what happens when a single ultrasonic **First order** sound wave is transmitted from a transducer and reflected back to a receiver (Figure 15). As the wave propagates through the air anything in its path causes the wave to bounce off in a new direction. Some of these reflected waves will find their way back to the receiver. During that bounce, energy will be lost. If the wave bounces a second time more energy is lost (**Third order wave**). For the rest of this section we will concern ourselves with **Second order waves** only, that is only waves that have bounced once. All other orders of waves will be treated as noise. These waves will have maximum energy and produce the largest signal. Figure 16 shows what the return trace looks like from our target layout Figure 15.

Short Transmit Pulse.

The first noticeable problem in Figure 20 is that targets 5 and 3 appear to be next to each other when in fact they are furthest apart. This is because our mono trace is one dimensional, we have no X or Y components only a Z component.

The second problem is that all targets returned a good wave. There is a high probability that this would not happen in practice because of anti-phase from closer targets.

The third problem is that target 2 cannot return a second order wave, as target 4 is in the line of sight. Any wave returned from target 2 will not show its correct distance. The trace of target 2 in Figure 16 shows that a fourth order wave is actually returned (B.) when the real distance is (A.).

In order to help overcome the second problem we can increase the pulse length or change the transmit frequency. Problems 1 and 3 cannot be overcome in mono, only multi-channel can help with these problems. That is by using more than one channel associated with more than one receiver. Figure 17 shows what the trace looks like if we increase the pulse length.

Long Transmit Pulse

The trace returned in Figure 17 shows that targets 5 and 3 have merged. The DPDD is designed to find these things (see hardware section; the DPDD of Figure 2). The PD pulse width is measured to a resolution of the CPU timer or clock, and this translates into a phase shift from the transmitted phase. As the stored DATA is the phase difference relative to the transmitted phase, it is a simple case of subtracting one DATA byte from another to produce the phase difference between them. By scanning the stored trace we can compare the phase of a cycle to that of its

neighbours, so as to detect correlated relationships within groups of pulses, to a resolution of <u>**Minimum Phase Shift**</u> as shown in the following table:

Table 2

High Resolution	For Inline Pulses	For Reflective Pulses
Minimum Phase Shift f= Transmit Frequency	$\frac{2\pi f}{\text{Clock}}$	$\frac{2\pi f}{2\ \text{Clock}}$
Resolution	$\frac{\text{Speed of Sound}}{\text{Clock}}$	$\frac{\text{Speed of Sound}}{2\ \text{Clock}}$
Low Resolution **Minimum Phase Shift** f = Transmit Frequency	$\frac{2\pi f}{\text{Timer Rate}}$	$\frac{2\pi f}{2\ \text{Timer Rate}}$
Resolution	$\frac{\text{Speed of Sound}}{\text{Timer Rate}}$	$\frac{\text{Speed of Sound}}{\text{Timer Rate}}$

Where Targets Merge

Figure 18(a) shows an expanded trace where the reflections from targets 5 and 3 merge. Example 3 shows the numbers the DPDD would produce from the middle of the parts A, B and C. These numbers show no noise or target corruption and are for demonstration purposes only. As we can see in the example A of Figure 18(b) there is a phase difference of zero up to the point where target 3 merges with target 5. At this point there is a phase shift and the numbers change as the signals from targets 5 and 3 combine, they then settle back to a phase shift of zero (Example B) and start to change again as the return pulse of target 5 ends (Example C).

Defining a Target

A basic target could be defined as:

1. PH = Maximum Phase shift allowed between consecutive cycles (1 = **Minimum Phase shift**).
2. N = Minimum number of consecutive cycles with a phase shift <= PH.
3. P = Minimum number of consecutive cycles with no phase shift.

Target Quality would depend on:

1. TN = Total number of consecutive cycles with a phase shift <= PH
2. TP = Total number of consecutive cycles with no phase shift.

Target position would be:

1. DN = Distance to start of TN (1 = **Resolution**).
2. DP = Distance to start of TP (1 = **Resolution**).

Using the definition PH = 2 and N = 5, Targets 5 and 3 in Example 3 would produce three targets instead of two. As we are only interested in a target moving from one point to another, we can still tell what target is moving because two targets will move at the same rate showing us that the two are related.

Some applications of the invention to surveillance of a monitored zone

The term 'monitored zone' is used to cover the field (volume) of view of the ultrasonic receiver, objects within this field being capable of receiving pulses of ultrasound emitted by the transmitter.

The monitored zone can be, for example, a room when it is desired to monitor intrusion into the room and/or removal of an object from the room,

or the monitored zone may be a relatively small volume such as a baby's cot.

Figures 19 and 20 show typical phase maps produced by operating the system of Figure 12. A great deal of information can be derived from such phase maps.

All rooms/areas being monitored would have a unique phase map associated with them regardless of the lack of movement at the time/times of the sample/samples being taken. The position of a static object within the area is identifiable by certain characteristics within the phase map. The phase map is generated by the position of a wave front (0-180°, Y axis) being received within a time slot (X axis). The introduction of a new object or the removal of an existing object within that area will change the phase map to one degree or another. If an object is introduced in the line of sight of the monitor then, not only can the change be recorded and action taken according to specified rules, but the relative position of the object can be plotted from the earliest disturbance at t_1 to the phase map along the X axis. The removal of an object will show a corresponding change to the phase map but in the negative.

Thus in Figure 19 the presence of an object is shown by the phase changes in the region between times t_1 and t_2, the waves reflected from the nearest part of the object being received at time t_1 and from the furthest receiver - visible parts of the object at time t_2. The shape of the phase-time profile between t_1 and t_2 can be considered as a phase-time sub-profile indicative of the object.

The point that is not made above is that in order for an object to be removed or added then there must be movement taking place and provided that the scan rate is sufficiently rapid then this must, of course, be detected at the time by detecting the phase change in that portion of the trace resulting from the presence of the object. Of course, the position of times t_1 and t_2 will also change.

The surface area of an object is generally in direct proportion to the degree of disturbance of the phase map beyond the object causing the disturbance and this, coupled with the range data t_1 can therefore be used to produce a calculated mass for the object. It will be appreciated that this enables rules to be established that distinguish between small and large objects.

This can have important practical uses since it is possible, for example, to ignore a cat moving in a monitored room, or a fly landing in a baby's cot.

The training of the device referred to is achieved by an initial mapping procedure which produces a distance to first object at switch on and can therefore be instructed, if desired, to alarm on any disturbances to the phase map at an earlier time slot to the original first object (within a reasonable tolerance if required), that is, to any disturbance along the x axis of Figure 19 at a time less than t_1.

Where the monitor is being used to look for removal of a specific object, such as a baby from a cot, or a picture from an art gallery, the removal of the object is monitored by the inverse of the above rule ie the initial map will contain the range t_1 to first object and, upon removal of the object, the range to first object will increase and the shape of the phase map beyond will drastically change enabling the software to make its decision on the

removal of the object. That is, the software can be arranged to look at the local shape of the phase map in the region just beyond the range to first object, and when this shape is found to vary by more than a predetermined amount, an alarm can be initiated.

A requirement to ignore a particular moving object while continuing to look for disallowed activity is (in the case of the new born baby) dealt with by specific algorithms applicable to that application. The environment is of a known shape and size. The monitor is at a constant height above the baby (as in Figure 2 of WO94/20021) and the beam is, as a result of the above, confined to the inside of the container. The normal movements of the baby can be allowed because they fall within an allowed phase map disturbance range. A hand or other large object can be arranged to cause an alarm because of the type and degree of difference. In other applications of the invention to monitoring a region which contains a moving object, the same principle would apply but with different algorithms.

It is also possible to compile a database, from experience, of a range of false alarm movements that are to be ignored. The analytical ability of the system is largely achieved by the degree of data acquisition the system is capable of and the history of the previous maps it maintains. Not only can we establish a calculated mass/range for the object but can take a view on the logic, or otherwise, of the history of the movements of the object. An example follows:

A curtain flapping as a result of a draft of air (either transitory or constant) can be viewed in the following way. Is the apparent mass within the rules for identifying a human intrusion. If yes then we look at the history, such as the previous ten cycles, and establish if the movement is going anywhere

(significantly towards/away from monitor or across the field of view) or just oscillating. In the case of the curtain the likely scenario is that of oscillation and can therefore be ignored.

The detection of fire in the monitored zone can be achieved by monitoring of the static phase map, in individual time slots, and as a whole, as a separate activity, the resulting data being monitored for single direction shifting of the entire map. The degree of shift is in direct proportion to the rise in ambient temperature of the area being monitored. The speed of change coupled with the degree of change will give appropriate criteria which can be set to give a good fire detection ability.

CLAIMS

1. An ultrasonic monitor for detecting unauthorised movement of an object in a monitored zone comprising:

a) an ultrasound emitter adapted to emit ultrasound into the monitored zone, and an ultrasound receiver adapted to receive sound waves reflected from objects in the monitored zone,

b) pulse energisation means for causing the emitter to emit a burst of ultrasonic oscillations,

c) detection means responsive to the receiver to monitor the output of the receiver, the detection means being arranged to determine the phase of the individual ultrasonic oscillations in the reflected waves received by the receiver, the phase being measured relative to the phase of the oscillations transmitted, and for a cycle of operation of the emitter in which one burst of ultrasonic oscillations is emitted and the reflected waves received by the receiver are examined, the detection means records against time in the cycle the phases of the individual received pulses, so as to produce a phase-time profile (or database) for that cycle, and the detection means being arranged to compare the phase-time profile of a later cycle with the phase-time profile of one or more earlier cycles and to produce an alarm signal in response to a difference between phase-time profiles which exceeds a predetermined difference.

2. A monitor as claimed in claim 1 in which the unauthorised movement comprises movement of an existing object in the monitored zone.

3. A monitor as claimed in claim 2 in which the unauthorised movement is movement associated with removal of an object from the monitored zone.

4. A monitor as claimed in claim 1 in which the unauthorised movement is the introduction of a new object of predetermined characteristics into the monitored zone, the arrangement being such that the movement is detected by recognising in the phase-time profile a local phase-time sub-profile indicative of an object of predetermined characteristics.

5. A monitor as claimed in claim 4 in which the sub-profile is indicative a person being present in the monitored zone.

6. A monitor as claimed in claim 4 or claim 5 in which the distance of a detected object from the emitter and receiver is assessed by monitoring the time in the phase-time profile at which the reflected burst of ultrasonic oscillations is received relative to the start of the cycle, and a calculation of the overall size of the new object is made, the overall size of the new object being used to determine whether or not to initiate an alarm signal.

7. A monitor as claimed in any of the preceding claims in which the arrangement is such that the phase-time profile of the current cycle is compared with the phase-time profile of the immediately preceding cycle in order to detect differences in the successive phase-time profiles, which

differences indicate changes in the position of an object within the monitored zone.

8. A monitor as claimed in any of the preceding claims in which the arrangement is such that the current phase-time profile is compared with a pattern of changes identified from a comparison of the phase-time profiles of a series of recent cycles, and if the pattern is considered to be a predetermined authorised pattern, and the latest phase-time profile is in accordance with the pattern, then that component of change in the phase-time profile between the current cycle and the immediately preceding cycle which satisfies the pattern, is ignored in determining whether or not to initiate an alarm signal.

9. A monitor as claimed in any of the preceding claims in which the detector means is arranged to identify in the phase-time profile group portions of the profile that have common characteristics with their neighbouring portions of the trace, and the detection means is arranged to identify group movements with purpose.

10. An ultrasonic monitor for monitoring the security of an object, hereinafter referred to as the 'monitored object', comprising:

a) an ultrasound emitter adapted to emit ultrasound into a region in which the monitored object is located in use, and an ultrasound receiver adapted to receive sound waves reflected from the monitored object,

b) pulse energisation means for causing the emitter periodically to emit a burst of ultrasound oscillations,

c) detection means responsive to the receiver to monitor the output of the receiver and to measure the phase of received ultrasonic waves relative to the phase of the emitted waves to provide phase difference signals, and wherein the detection means is arranged to discriminate between said monitored object and other objects in the field of view of the receiver by analysing the sequence of said phase difference signals pulse by pulse (these pulses are the individual oscillations, ie wave cycles of the received ultrasonic signals), and by identifying correlated relationships within groups of said pulses, and to memorise those relationships as representing respectively the different objects in the field of view, and wherein

d) the detection means during a subsequent monitoring cycle is arranged to compare relationships of the phase difference signals with the said memorised relationships so as to identify intrusion into said field of view of a new object, and being arranged to produce an alarm signal on detection of the intrusion of said new object.

11. A monitor as claimed in claim 10 in which the detection means comprises a new object discriminating means which is adapted to inhibit the production of an alarm signal in response to the intrusion of a new object of a predetermined range of characteristics.

12. A monitor as claimed in claim 11 in which the predetermined range of characteristics is a range of dimensions of the new object, whereby an alarm signal is only generated by the intrusion of certain sizes of new object into the field of view.

13. A monitor as claimed in claim 12 intended for monitoring of a baby, the detection means being trained or pre-set to respond to the introduction of a hand or implement into the field of view to initiate an alarm signal.

14. An ultrasonic monitor for detecting an intruder in a monitored zone comprising:

a) an ultrasound emitter adapted to emit ultrasound into the monitored zone, and an ultrasound receiver adapted to receive sound waves reflected from objects in the monitored zone,

b) pulse energisation means for causing the emitter periodically to emit a burst of ultrasound oscillations,

c) detection means responsive to the receiver to monitor the output of the receiver and to measure the phase of received ultrasonic waves relative to the phase of the emitted waves to provide phase difference signals, and wherein the detection means is arranged to discriminate between various objects in the field of view of the receiver by analysing the sequence of said phase difference signals pulse by pulse (these pulses are the individual oscillations, ie wave cycles of the received ultrasonic signals), and by identifying correlated relationships within groups of said pulses, and to memorise those relationships as representing respectively the different objects in the field of view, and wherein

d) the detection means during a subsequent monitoring cycle being arranged to compare relationships of the phase difference signals with said memorised relationships so as to identify intrusion into said field

of view of a new object, and being arranged to produce an alarm signal on detection of the intrusion of said new object.

15. An ultrasonic monitor for detecting an over-temperature situation in a monitored zone comprising:

a) an ultrasound emitter adapted to emit ultrasound into the monitored zone, and an ultrasound receiver adapted to receive sound waves reflected from objects in the monitored zone,

b) pulse energisation means for causing the emitter to emit a burst of ultrasonic oscillations (each burst of ultrasound comprises a plurality of oscillations),

c) detection means responsive to the receiver to monitor the output of the receiver, the detection means being arranged to determine the phase of the individual ultrasonic oscillations in the reflected waves received by the receiver, the phase being measured relative to the phase of the oscillations transmitted, and for a cycle of operation of the emitter in which one burst of ultrasonic oscillations is emitted, and the reflected waves received by the receiver are examined, the detection means records against time in the cycle the phases of the individual received pulses, so as to produce a phase-time profile (or database) for that cycle, and to the detection means being arranged to compare the phase-time profile of a later cycle with the phase-time profile of one or more earlier cycles and to produce an alarm signal in response to an overall time shift of the phase-time profile greater than a predetermined time shift.

16. An ultrasonic monitor substantially as described herein with reference to the accompanying drawings.

The Patent Office

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Claims searched: 1-9,15

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1G (GPGX)

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Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X,Y	GB2115151A	(BRADFORD) see particularly page 2 lines 77-79	1 at least
A	GB2090411A	(TOKYO SHIBAURA)	
Y	WO94/20021A2	(ADVANCED MONITORS)	1 at least
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